Method and device for combining images from at least two light projectors

The invention is used to accurately and efficiently calculate the contribution from each light source when combining multiple light sources to give the same light intensity and colour as if a single light source was used.

This can for instance be used to create a smooth transition between the projected images between two or more projectors. In the overlapping area the projectors must be combined to create the same intensity and colour as if a single projector was used.

The use of multiple projectors has been known for a long time. In slide shows more or less overlapping images has been used to provide different visual effects. For these purposes different types of masks have been used to provide the transition between the images. These masks may be sharp edges or define smooth, gradual transitions. By adjusting the masks and the projectors, seamless transitions between adjacent or overlapping images are provided.

Using video projectors a similar solution is provided in Canadian patent CA 2,025,624 and US 5,136,390, in which the masks are applied electronically. This has, however the disadvantage that the quality of the transitions are dependent on the projectors, as the projectors' response to input data varies to a large degree between different projectors and with the projector age.

US 6,115,022 describes a related method in which selected parts of the overlapping areas of the images are monitored, both regarding colour and intensity, in real time so as to secure the image quality in the selected parts. This represents an improvement over the previous solutions but requires more processing while displaying the images and is dependant on selecting relevant parts of the overlapping area.

It is thus an object of this invention to provide a smooth transition between projected images with built in compensation for colour and intensity variations between the

projectors. This is obtained by a method and a device being characterised as described in the independent claims.

The invention is thus based on the fact that the intensity and colour in each point of the overlapping area is known through the transfer function, and that the characteristics of each projector is measured. The input to each projector is then adjusted so that the sum of the light from all the projectors aimed at a point is equal to the transfer function at this point using red, green and blue, as well as the blending factor deciding the percentage of the total intensity at each point each projector should provide. In practice these data for each projector is provided as an interpolated, tabulated function.

The present invention will be explained more in detail below with reference to the accompanying drawings, illustrating the invention by way of example.

Figure 1 illustrates errors in intensity using empirical approximations of the light intensity in the transition area between two projectors.

Figure 2 illustrates the mixing of light from two sources.

Figure 3 illustrates the transfer function of a light source.

Figure 4 illustrates two projectors projecting two partially overlapping images on a screen.

A projector usually projects 3-4 colour components (red, green, blue and white/clear) for each pixel. Each combination of pixel and colour component can be considered as independent light sources and should be treated separately.

A light source has a TF (transfer function), i.e. given an input you get a certain colour and intensity. The TF function can be calculated or measured. The TF might also have other parameters that should be taken into account, e.g. brightness/contrast adjustment capability on a projector. As mentioned above there are individual differences in the TF between projectors e.g. depending on deterioration with age, differences in A/D converters and lamp types.

Existing methods for combining light sources to give the same colour and intensity usually has the weakness in that they do not take into account the intensity transfer

function, but they create an empirical transition. Figure 1 illustrates the problems related to this solutions, where x is the position in the edge blending transition between two images, and y is the expected intensity divided by actual intensity. As is evident from the drawing several errors may occur. In this example a dark colour **a** is too bright in the transition area, while two brighter colours **c**, **d** is too dark in the transition area, even though the empirical approximation was adjusted to a typical colour and the intensity **b** is flat as expected.

Example: Referring to figure 2 two at least partially overlapping video projectors 1,2 are used for obtaining a combined image 5 from two separate images image 3,4 shown on separate screens. The system shown in figure 2 comprises a computer or similar storing and controlling the two images 3,4 which are to be combined, and a control unit 6 controlling the projectors 1,2 based on the stored characteristics of each projector. The control unit may comprise per se known means for analysing the projector characteristics, e.g. during start-up, or for receiving such information, e.g. from the computer 7.

Referring to figure 4 the combined image 11,12 have a transition zone 13 where each point is represented by both projectors with chosen intensity and colour. A preferred method will usually be to transition in the overlapping area from one dominating projector to another dominating projector, thus to provide a gradual transition between the two. Each point in the transition zone may be viewed as the mixing of two light sources, two light sources are combined as follows:

$$i_{lightsource1} = \beta * i_{original}$$

$$i_{lightsource2} = (1 - \beta) * i_{original}$$

- $i_{lightsource1/2}$ input to the light sources
- $i_{original}$ original input to the light source before the transition

- β, 1- β – mixing relationship, sums to 1 for all light sources involved(two in this case). Normally β is chosen as x/(width-1), where x is position in overlap(starting at 0) and width is the width of the overlap in pixels.

The weakness of this method is that it will not give an even light intensity and colour if the TF is not linear and monochromatic. In these cases it is common to create an empirical adjustment, e.g.

$$i_{lightsource1}=1^{(t/T)/\gamma} * i_{original}$$

The formula is as above, but with a parameter (γ) that is tweaked to get the best possible visual result. This may work reasonably well for a specific value of $i_{original}$, but the resulting intensity can be too high or low for other input values (See Fig 1). The result is further worsened when the light source does not have a monochromatic TF.

In prior art, it is a common assumption that each input controls each output colour indepdentently. In this case the projector can be treated as an intensity transfer function(ITF) for each input. This is clearly wrong where a projector has red, green, blue inputs and red, green, blue and white/clear output, but it can also be a wrong assumption for projectors that have red, green and blue input/outputs depending on the TF.

Creating edge blending effects when a projector has an ITF is much simpler than when it has a TF and unless the complications caused by the TF are treated explicitly, it must be assumed that prior art refers to the simpler case of projectors only having an ITF.

The present invention does not exhibit the abovementioned weaknesses as it takes into account the TF (Fig. 1). For the case above, we have:

$$i_{lightsource1}=TF_1^{-1}(TF_1(i_{original})* \beta)$$

$$i_{lightsource2}= TF_2^{-1}(TF_2(i_{original})*(1- \beta))$$

- $i_{lightsource1/2}$ input to the light sources
- $i_{original}$ original input to the light sources
- β – as above
- $TF_n(x)$ is the transfer function, as illustrated by figure 3, which evaluates to light intensity and colour for each light source, in this case for an F1 projector from projectiondesign.com.(Photographic mode). Normally the TF is monochromatic, i.e. only the intensity and not the colour changes in response to the input. If the colour as well as intensity changes based upon input, $TF_n(x)$ is not a scalar but a vector, normally of size 3. The size of the vector owes its heritage to the eyes ability to distinguish three colours. Ref: tristimulus CIE XYZ in "Computer Graphics – Principles and practice" by Foley, van Dam, Feiner and Hughes, published by Addison Wesley Publishing Company, ISBN 0-201-12110-7.

  $TF_n(x)$ is of arbitrary units such that $TF_n(x)= \beta TF_n(x) + (1- \beta)TF_n(x), \beta \in [0,1]$.

  Multiple light sources can be combined and together have a single TF, e.g. projectors with red, green, blue and white components have a single TF(RGB)=XYZ
- $TF_n^{-1}(x)$ - mathematical inverse of $TF_n(x)$. Sometimes $TF_n^{-1}(x)$ is not defined for values of x, in which case an approximation can be good enough for practical purposes.

If the TF is slightly different for each light source, there will be a smooth transition from the colour and intensity in one source to the colour and intensity in the other light source.

This invention purposly does not try to compensate for variations in the TF(e.g. lamp colour, spatial colour/intensity variations). The problem with trying to compensate for differences in the TF is that projectors generally have a limited dynamic range in its inputs(typically 256 levels), and any attempts at compensating for differences in TF

invariably end up reducing the dynamic range, which rapidly causes disturbing effects. A much better approach is to take advantage of the human eyes tendency to ignore differences in colour and intensity that varies only slightly per angle. A typical example of where projectors take advantage of this approach today is for light intensity. The light intensity for a projector in its corners is typically 75% of its maximum(in the center), yet it is perceived by most people as uniform intensity.

In figure 2 and 4 an embodiment of the invention is illustrated in which two projectors 1,2 are used to create a smooth transition 13 between two projectors edge blending. Referring to fig 1, figure 4 shows how a single projected pixel in the overlapping area consists of six independent light sources, red, green, blue from projector 1 and 2 respectively. In this case the projectors have the following features:

- Independently controllable colour components, i.e. it can have a white component as long as it is independently controllable. For a projector the white component is not normally independently controllable from the outside and the invention would have to be embedded into the projector.
- the TF varies only in intensity.

Each combination of colour component and pixel can in this case be treated separately and in the same manner. Only the light intensity changes in response to the input, hence the transfer functions are actually intensity transfer functions and can be written as:

$$ITF_{red/green/blue}(i_{red/green/blue})=intensity$$

Where

- $i_{red/green/blue}$ – red, green or blue input value (typically between 0..255)
- intensity – a scalar value between 0..1 when multiplied by $I_{colormax}$ gives actual colour and intensity
- $ITF_{red/green/blue}(i_{red/green/blue})$ – measured or as in the case of figure 1 given by manufacturer in tabularized form
- $I_{colormax}$ – colour vector for maximum light intensity for colour component

For edge blending we also need to know ITF_1^{-1}(intensity). ITF_1^{-1}(intensity) can be calculated, e.g. using a binary search algorithm on ITF(), and tabulated.

For a single colour component the input to the projectors to blend a single colour component is calculated as follows:

$$i_{projector}=ITF^{-1}(ITF(i_{original})*\beta)$$

- $i_{projector}$ edge blended color input to the projector
- $i_{original}$ the input to the projector to show the desired pixel when no edge blending in use
- β – mixing factor. β for one projector and (1- β) for the second. Transitions from 0 to 1 in the overlapping area.

Since the edge blending takes place in real time, a practical implementation must be very fast. With a projected resolution of 1280x1024 pixels x 60 Hz, this can be implemented using a modern FPGA (e.g. the Xilinx Virtex-II family). In one embodiment of the invention the following parameters outlines how this was implemented:

- ITF and ITF^{-1}were implemented as tables with sufficient precision and size to ensure that $c \approx ITF^{-1}(ITF(c))$
- Interpolation to improve accuracy of ITF^{-1}
- ITF implemented as a table lookup. 256 entry table of 16 bit integer.
- ITF^{-1} implemented as a table lookup. 512 entry table of 8 bit integers
- $ITF(i_{original})*\beta$ implemented as (16 bits * 9 bits integer multiplication)/256
- β was decremented from 256 to 0 in the overlap range using mid-section line drawing algorithm

If the projectors have red, green, blue and white components, the discussion above still applies, with the exception that there are various complications related to the TF() of the two identical projectors. The inputs to these projectors are still red, green and blue. Although each of the red, green, blue and white segments have separate independent TF, they are not separately controllable. The combined TF for all the combined colour components is:

$$TF(RGB) = XYZ$$

- RGB – colour input vector to projector
- XYZ – response vector. For practical purposes XYZ are normalized to be in the range [0..1,0..1,0..1]

TF(RGB) is in this embodiment either given by manufacturer or measured. This can for instance be done by measuring a large number of samples in the RGB cube and interpolating the rest of the values. E.g. 64x64x64 samples when measured 1 sample/ second would take ~ 3 days. With a fast measurement device, e.g. 20 samples a second, it is quite feasible to measure the full range of colours for a projector with 256x256x256 RGB combinations (~10 days). Normally the TF(RGB) is trivially calculated and hence it is preferable to deduce the function or have it provided by the manufacturer.

In this case it is non-trivial to find $TF^{-1}(XYZ)$ and in some cases it might not even exist, in which case an approximation might be good enough for practical purposes. One method is to use a downhill simplex simulated annealing optimization algorithm, e.g. as described in "Numerical Recipies in C++ Second Edition", by William H. Press, Saul A. Teukolsky, William T. Vetterling and Brian P. Flannery, published by Cambridge University Press, ISBN 0 521 75033 4), i.e. find RGB such that the expression below is as close to 0 as possible:

$$|TF(r,g,b)-XYZ|$$

The RGB value to input to the projector to do the blending is then calculated as follows:

$$RGB_{blendedpixel}(RGB_{original}, \beta)=TF^{-1}(TF(RGB_{original})*\beta)$$

The formula above is not practical to implement in hardware. An alternative is to tabulate the resulted blended colours of the formula above and then interpolating the resulting blended pixel. Although TF can normally be calculated efficiently with great accuracy, the same is not the case with TF^{-1}. To be calcualted quickly enough for edge blending purposes, it would have to be implemented as a multidimensional stored table. Since the size of a complete tabulation of TF^{-1} is impractial(2003, too large), some means of interpolation will have to be used. Multidimensional interpolation is known to be problematic, and it will give especially poor results on TF^{-1} due to TF^{-1} shape. Typically these interpolation problems manifest themselves as moire like artifacts in the transition between two projectors.

A much better approach is to interpolate $RGB_{blendedpixel}(RGB_{original}, \beta)$ as the shape of this function is much better suited for initerpolation. During tabulation of $RGB_{blendedpixel}(RGB_{original}, \beta)$, TF^{-1} is not approximated but calculated accurately using e.g. downhill simplex simulated annealing optimisation algorithm mentioned above. This procedure is computationally expensive, hence it should be calculated ahead of time. If the TF changes(as would happen when e.g. adjusting the "colour temperature" or gamma curve in a projector), some time will pass before $RGB_{blendedpixel}(RGB_{original}, \beta)$ can be retabulated.

In one embodiment a four dimensional table (3x3x3x16, RGBβ) was created for $RGB_{blendedpixel}(RGB_{original}, \beta)$ and linear interpolation was used. The size of the table is a compromise between hardware requirements and quality required.

It is practical to implement this blending in hardware using a modern FPGA (2003).

One practical aspect of video signals and the TF is signal transmission technology, e.g. an analogue VGA signal is sampled to a digital signal or transmitted digitally using a DVI cable. With a DVI cable, there is no signal loss, but the cable length and bandwidth

is more limited than for a VGA cable. If multiple VGA sources are combined as above to a single picture, the errors introduced during the conversion from analogue to digital data can have a substantial negative impact (cable length, slight calibration differences, etc.). Normally it is possible to adjust the A/D conversion to set the 0 level and the dynamic range, frequently described as adjusting brightness (0 level) and contrast (dynamic range). In one embodiment of the solution, a known test image was displayed and the sampled pixel was compared, and based upon this the contrast and brightness for the A/D conversion was automatically adjusted. The reason why the A/D conversion is as critical as when combining multiple images as above is that the TF is very steep, i.e. a small offset/dynamic range error has a large impact on the displayed colour and intensity. The invention therefore also relates to an automatic adjustment method of analogue to digital input video signal conversion using a known input signal and comparing with a resulting digital video signal. This may be obtained by adjusting the zero offset and dynamic range automatically according the result of the comparison.

To summarise; the invention relates to a method for combining images from at least two light projectors, the images having a transition zone between them, wherein the dimensions of the transition zone is known, and the emitted light toward the transition zone from each projector is based on a predetermined transfer function from input signal to projected image for each projector in the transition zone, so as to obtain predictable image characteristics in the transition zone.

The transition zone may be, as illustrated in figure 2, the overlapping parts of two adjacent images. It is, however, clear that the transition zone may be of different types and shapes, e.g. if an image from one projector is surrounded by the image from another projector.

As stated above the method according to the invention may comprise the step of interpolating between the light characteristics of a first projector to the light characteristics of a second projector over the image transition zone area, so as to provide a smooth transition between the projected images. In most cases the transition zone is the same as the overlapping part of the images, but other situations may be

contemplated, e.g. in the transition between adjacent, non-overlapping images. This may apply if there are large differences between two projectors and the interpolation requires a smoother transition than available in a small overlapping area. This is of course limited by the available variations in the projectors intensity and colour room.

Also as stated above the transfer function may be calculated from known characteristics of the projector or measured by providing a known signal to the projector, measuring the emitted light and calculating the transfer function from the measured relationship between applied signal and measured light characteristics. The applied signal may be a ramp from zero output intensity to full output intensity of the projector, a process which may be performed as an automatic part of the start up procedure of the system and projectors.

The control device according to the invention for at least two image projectors being adapted to project overlapping images at a surface and defining a transition zone between the images from each projector, the device comprising memory means for storing a transfer function for each projector, said transfer function describing the relationship between input signal and emitted light of each projector, and calculating means for applying said transfer functions on said input signal so as to obtain a predictable image characteristics in the transition zone between the at least two projected images.